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INFRARED SPECTRA OF CRYSTALLINE AND GLASSY SILICATES AND APPLICATION TO INTERSTELLAR DUST

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Glassy silicates have been identified as components of interstellar and circumstellar dust on the basis of agreement in the position and shape of observed bands near 10 and 20 microns with laboratory spectra of glassy silicates, particularly of olivine ($(\text{Mg}, \text{Fe})_2\text{SiO}_4$) composition (See Dorschner and Henning, 1986 for a review of the experimental investigations). Olivine is but one of a variety of silicates that are predicted to condense from a cooling gas of "cosmic" composition in oxygen-rich stars. Other predicted condensates include the "refractory" ($> 1000^\circ\text{C}$) silicates diopside ($\text{CaMg}(\text{Si}_2\text{O}_6)$) and enstatite ($(\text{Mg}, \text{Fe})\text{SiO}_3$) as well as "low temperature" hydrous minerals including serpentine ($\text{Mg}_6(\text{Si}_4\text{O}_{10})(\text{OH})_8$) and talc ($\text{Mg}_3(\text{SiO}_{10})(\text{OH})_2$) (Huffman, 1977). Both refractory and hydrous minerals have been found in meteorites, and recently in interplanetary dust particles collected in the Earth's stratosphere (Zolensky, 1987)

The infrared spectra of crystalline minerals predicted in theoretical condensation sequences do not match the astronomical observations. Since the astronomical spectra are a closer match to glassy silicates, we have undertaken a study to measure the infrared spectra of glassy silicates that have compositions similar to silicate minerals predicted in theoretical condensation sequences. The data should support observations aimed at elucidating condensation chemistry in dust forming regions.

We measured the mass absorption coefficients, from 2.5 to 25 microns, of ground samples of olivine, diopside, and serpentine and also smoke samples that were prepared from these minerals. The smoke samples prepared in this way are predominantly glassy with nearly the same

composition as the parent minerals. The crystalline samples consisted of pure olivine ($(\text{Fe}_{0.1}\text{Mg}_{0.9})_2\text{SiO}_4$), serpentine, and diopside. Sample purity was confirmed by X-ray diffraction. Each mineral was ground for 10 hours and a measured mass of the powder was mixed with KBr powder for absorption measurements using the method of Borghesi et al. (1985). The smoke samples were prepared from the same samples used for grinding by vaporizing the minerals using pulsed laser radiation in air. The smoke samples formed by condensation of the resulting vapor. The smoke settled onto infrared transparent KRS-5 substrates and onto a quartz crystal microbalance used to obtain mass measurements. A description of the preparation method is given in Stephens (1980). The glassy diopside showed only diffuse electron diffraction peaks and hence was nearly amorphous, while the serpentine smoke showed a weak diffraction pattern corresponding to MgO. The smoke from olivine showed a weak diffraction pattern corresponding to Fe_2O_3 and/or Fe_3O_4 .

The mass absorption coefficients, from 2.5 to 25 microns, of crystalline diopside, olivine, and serpentine and their corresponding smoke samples are shown in Figures 1, 2, and 3.

Figure 1 - Diopside Spectra

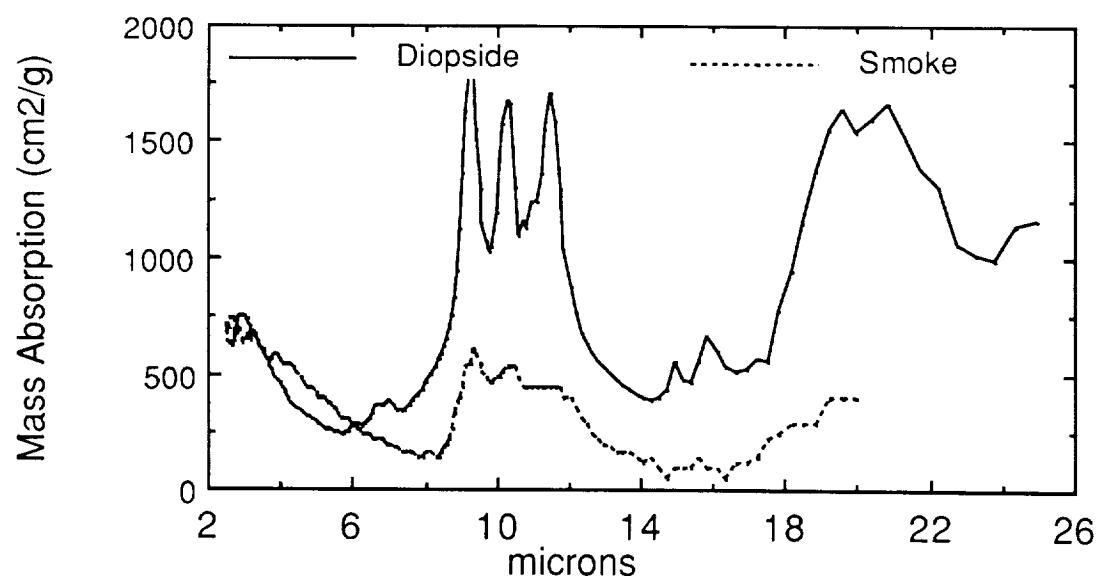


Figure 2 - Olivine Spectra

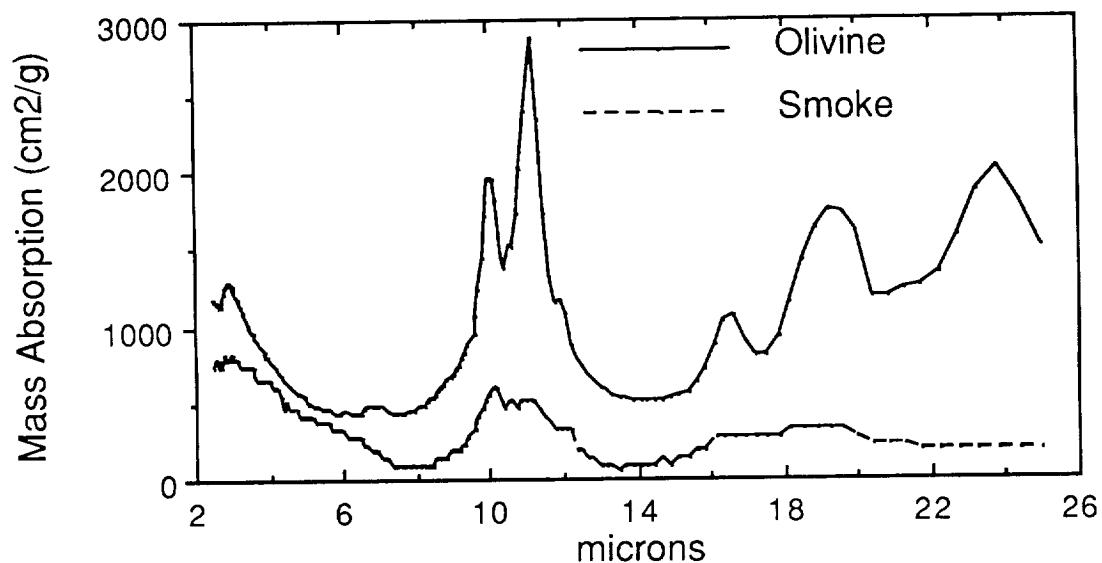
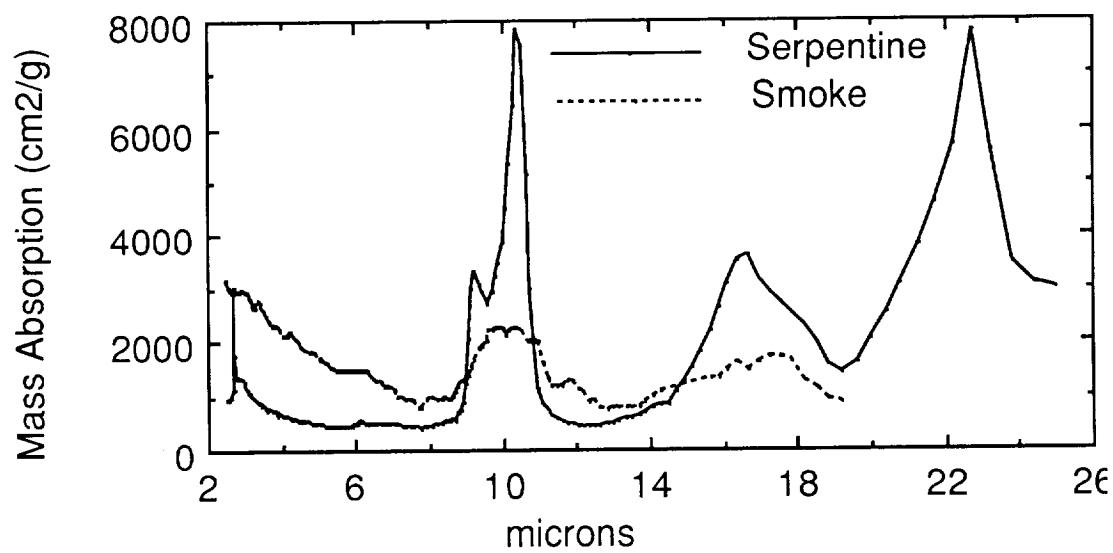


Figure 3 - Serpentine Spectra



The spectra for the ground crystalline samples show sharp peaks with peak positions and mass absorption coefficients similar to spectra in the literature (diopside (Omori, 1971), olivine (Day 1975), and serpentine (Dorschner et al. 1978)) All of the crystalline samples show a broad spectral peak near 3 microns due to water absorbed during the grinding processes. The crystalline serpentine sample shows a sharp peak at 2.7 microns from OH stretching.

The smoke samples show broader and weaker peaks that are centered near the major peaks in the crystalline spectra. The serpentine smoke does not show a peak corresponding to the 2.7 micron peak in the crystalline serpentine, since the smoke does not have a layered hydrous structure. The mass absorption coefficient at the 10 micron peak of the olivine smoke is much less than the value of $1750 \text{ cm}^2/\text{g}$ reported by Kratschmer and Huffman (1979) for amorphous olivine. Mass absorption coefficients of diopside and serpentine smokes have not been reported, but Dorschner et al. (1980) measured peak mass absorption coefficients in the range of 2000-3000 cm^2/g for a variety of Fe, Ca, and Mg protosilicates. Our serpentine smoke shows similar strength in the 10 micron feature. The range of mass absorption coefficients for the various smokes illustrates the danger of deriving dust and elemental abundances from measurements of the peak strengths in observational spectra of silicate dust. We do not presently understand the reason for the wide range of mass absorption coefficients in our smokes.

Interestingly, diopside and olivine smokes show very similar peak positions and strengths in the 10 micron band despite the range of metal cations (Fe, Mg, Ca) and metal to silicon ratios of the samples. The shape of the 10 micron peak of serpentine smoke is also similar to the other two smokes. This points out the insensitivity of the 10 micron peak to the composition and metal to silicon ratio of glassy silicates. The 20 micron features for the serpentine, olivine, and diopside smokes peak at 17.5, 19, and beyond 20 microns respectively. The weaker 20 micron silicate feature in astronomical objects we believe to be more diagnostic of the composition of glassy silicate dust than the 10 micron feature. The weakness of the 20 micron feature places strong requirements on the quality of observations needed to probe the condensation chemistry in astronomical environments.

The other striking feature of the spectra is the strong rise in extinction toward the near infrared. All of the spectra except serpentine show this trend. Stephens and Russell (1979) showed that much of the extinction seen in the near infrared spectra of ground samples of olivine is due to scattering by comparing emission (absorption) and extinction (absorption and

scattering) spectra. Emission spectra of the ground samples are needed to determine if the near infrared rise is due to absorption or scattering.

For smoke samples, which consist of smaller particles, the scattering is expected to be much smaller and the absorption should dominate. Preliminary data on the emission spectra of the serpentine and diopside smokes indicate, however, that the near infrared rise in serpentine is due to absorption, while that for diopside is due to scattering (Russell 1988). The difference in the scattering and absorption behavior of the two samples points out the difficulty in separating scattering and absorption in the near infrared and shorter wavelengths. Separation of absorption and scattering processes in this region are needed, for example, to understand the observation that circumstellar silicates show stronger absorption in the near infrared than terrestrial silicates (Jones and Merrill, 1976). More work needs to be done on synthesizing and measuring the spectral properties of a variety of silicates glasses over a wide range of wavelengths including the ultraviolet, visible, and infrared to obtain a comprehensive picture of the spectral behavior of these materials.

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